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DECOMPOSITION PROCESSES AND NUTRIENT RELEASE PATTERNS OF OIL PALM RESIDUES

Keywords: Oil palm residues, decomposition, decomposition rate, nutrient release.

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The decomposition patterns of the oil palm residues were found to show a decreasing remaining of dry matter in the order: leaflets > rachises = trunks > roots. The leaflets reached t_{50} at sir months, the rachises and trunks at eight months and the roots at 10 months. The decomposition rate constant ‘k’of the oil palm residues ranged from 0.13% to 0.22% day-’ in which the leaflets, rachises, trunks and roots had a value of 0.22%, 0.17%, 0.17% and 0.13% day^{-1} respectively. The controls regulating decomposition of oil palm residues during the study period have been shown to operate in the rank order: macroclimate > microclimate > resource quality > organisms. Rainfall distribution was the main climatic factor that controlled the moisture content ofresidual materials and the microclimate within different locations in the residue piles strongly modified the variation in temperature and moisture that affected the rate of decomposition. On the average, most of the oil palm residues were found to decompose within 12-18 months while some of the hardier materials, particularly roots, took much longer than 18 months to decompose. Significant accumulation of light organic carbon fraction on the soil surface will provide and relase nutrients to the soil.

Nutrients released from oil palm residues showed different release patterns between residue types and nutrients. The leaflets, rachises, trunks and roots all showed nutrient release in *the order: K>Mg=Ca>P>N. The release* ***of*** *nutrients* ***from*** *the residues was relatively quick, especially K, with more than 70%* ***of*** *the nutrients released. Generally, the release and* ***transfer of*** *nutrient to the soil pool occurred within the 18 months period.*

INTRODUCTION

In agricultural systems in the tropics, there is an increasing interest in using crop residues for improving soil productivity which can reduce the use of external inputs of inorganic fertilizer. With the adoption of zero burning in replanting oil palm, the residues left in the field represent a significant resource in terms of organic matter and plant nutrients. The value of these residues for maintaining soil fertility is generally recognized by the oil palm industry but little information is available on their decomposition rates and patterns of nutrient release to be used as a basis for refining fertilizer management practices (Loong *et* al., 1987). Similarly, although empty fruit bunches (EFB), palm oil mill effluent (POME) and other oil palm residues are recycled or utilized in the plantation, there is still scope for improvement in the management of these residues by working towards zero waste. Hence, the main foci of this study were to investigate the rate determinants of oil palm residue decomposition and the time over which the different mineral nutrients were mobilized from the residues of the old stand for the new planting.

Decomposition processes play an important role in soil fertility in terms of nutrient cycling and formation of soil organic matter. The decomposition rates of different plant materials under different environmental conditions had been studied extensively (Swift *et* al., 1979) with much research centred on the initial stages of decomposition when the rates can be simply estimated by periodic measurements of weight loss of the litter or residues.

Decomposition of plant residues involves changes in the state of the material through losses attributable to catabolism (K), comminution (C) and leaching (L) (Swift ***et al.***, 1979). K is the enzymatic degradation of microbial and animal enzymes of an organic compound changing it from a polymer to a monomer or to its mineral constituents. C is physical breakdown or a reduction in particle size by animal feeding activities and abiotic processes. L is the removal of water-soluble materials, an entirely physical process, although the rate of leachate losses is influenced by K and C.

These component processes ofdecomposition are regulated by three variables: the nature of the decomposer community (0) which represents the fauna and microorganisms, characteristics of the organic matter which determine its degradability, defined as resource quality (Q), and the physico-chemical environment (P) at the macroclimatic and edaphic (soil) or micro scales (Swift *et* al., 1979). These variables generally operate in a hierarchial manner (P > P microclimate > Q > O) with climate setting the limits within which materials of particular resource quality characteristics can be decomposed by saprotrophic organisms (Anderson and Swift, 1983). Under some circumstances, this hierarchy may change, e.g. when materials are so recalcitrant that they do not decompose rapidly under optimum climate conditions, or when termites attack materials under conditions too dry for microbial decomposition. As decomposition progresses, the chemical and physical composition of the original material changes and particulates, dissolved organic matter and micarbial secondary products are formed. Decomposition processes can therefore be visualized as a cascade of steps, each regulated by the complex of OPQ variables, with the KCL products moving to new environments where they are further processed.

The decomposition rates ofleaflets, rachises, trunks and roots of oil palm were investigated separately, using litter bags and cages of different sizes, to estimate the timing of nutrient release from the different residue fractions. The experiments were set up to determine whether the microclimates associated with locations of the materials in residue piles would affect their decomposition rates in a humid tropical environment. Changes in the standing crop of pulverized and chipped/shredded (C/S) oil palm residues were also monitored to obtain information on how reducing the mass of resource affected decomposition rates and release of nutrient in the plot scale studies.

MATERIALS AND METHODS

Decomposition in terrestrial ecosystems is commonly studied using the litter bag method (Wieder and Lang, 1982) which consists of enclosing plant material of known mass and chemical composition in a screened container. Initially, a large number of bags is placed in the field and, at each subsequent sampling, a random set of bags is retrieved and analyzed for loss of mass and/or changes in the chemical composition of litter or residues.

A particular problem of using litter bags is that the bag may prevent the litter or residues from close contact with the soil and hence the microclimatic conditions which affect decomposition may not be representative of those of the soil. Further, the bags also prevent natural incorporation of the litter or residues into the soil while compaction of the litter or residues can also create different microclimates affecting microbial activity. Despite these drawbacks, the litter bag method remains the most commonly used technique for examining litter or residue decompositionin terrestrial ecosystems. Although the method may underestimate actual decomposition, the results should reflect the trends characteristic of unconfined decomposing litter or residues and, as such, allow for comparison among species, sites, and experimental manipulations (Wieder and Lang, 1982).

Tian (1992) tested the access of soil fauna on decomposition and nutrient release of plant residues using various mesh sizes (0.5, 2 and 7 mm) and concluded that soil fauna significantly increased decomposition and nutrient release of plant residues of high and intermediate quality. However, the effect of soil fauna on decomposition of plant residues of extremely low quality was insignificant. In the present study, decomposition and nutrient release were studied using nylon litter bags with 4 mm mesh size which allowed access to most organisms involved in litter decomposition.

Preparation of Materials

The fresh materials, comprising leaflets, rachises, trunks and roots, to be placed in litter bags were prepared as follows:

Leaflets. The leaflets were collected and prepared from identical fronds 17 which were intermediate between new and old fronds. In practice, only the older fronds are cut during harvesting or pruning: thus, preferably, older fronds should have been used. Only leaflets from the middle part of the frond were used in this study. They were removed, cut to a length of about 30 cm and batches of about 200 to 350 g were placed in litter bags measuring 40 x 40 cm. The bags were tagged and clipped with wire. The fresh weight of each sample was recorded. A total of 216 litter bags of leaflets were prepared and used.

Rachises. Samples of rachises (including petioles) were prepared from the same fronds from which the leaflets were obtained. The fresh rachises without leaflets were cut into four pieces of equal length and weighed. They were then placed in tagged litter bags measuring 150 x 40 cm. A total of 108 bags were prepared.

Trunks. Trunk tissue was taken from the middle section of trunks to provide samples of intermediate quality. The trunks were sawn into approximately 30 cm length sections, each weighing 7 to 11 kg depending on the trunk diameter. They were placed in square mesh bins measuring 60 x 50 x 50 cm. A total of 108 mesh bins were prepared.

Roots. Fresh primary and secondary roots were used as samples for the decomposition study. The roots of felled palms were excavated and cleansed of any adhering soil. Known weights of fresh roots 150-250 g, were placed in litter bags measuring 40 x 30 cm and then filled with root free soil. The bags containing the roots and soil were then tagged and clipped with wire. A total of 144 bags were prepared.

In all cases, subsamples of the plant materials for decomposition and nutrient release study were taken for determinations of dry weight and initial nutrient contents.

The tagged litter bags and mesh bins containing the different materials were placed in the field on piles of oil palm residues at three positions: on top of the pile, in the middle, and at the bottom under the oil palm residues in contact with the ground. A complete randomized design was used with four replicates per treatment. Three bags of leaflets, one of rachis and one of trunk were placed at each position for the particular sampling interval. All the samples were left naturally to be covered by leguminous cover crops and weeds. Sampling was carried out at two-month intervals up to 12 months for leaflets and 18 months for rachises and trunks. At each sampling, the recovered materials in the litter bags were carefully separated from soil particles and weighed. Subsamples of recovered materials at alternate sampling dates were taken to determine the moisture content and contents of N, P, K, Ca and Mg.

In the case of roots, the bags were buried to a depth of 30-45 cm at two locations of old frond pile and old avenue. Three bags were buried for each sampling date. Samples were retrieved at two-month intervals for a period of 12 months. At each sampling, the root samples in the litter bags were water-cleansed, oven-dried at 80°C to constant weight and then weighed. Subsamples were taken and analysed for nutrient content.

Decomposition of C/S and Chipped and Pulverized (C/P) Materials in Bulk

The decomposition of C/S and C/P materials in bulk, consisting mainly of trunk and frond tissues, were studied in order to compare with the decomposition rates of single palm components in the litter bags.

Containers were constructed with 7 mm mesh heavy nylon netting in the form of a rectangular basket 1.5 m in length, 1 m width and 1 m height, and positioned in the inter-row.

Bulk samples ofvarious fresh mixed oil palm components (mainly the chipped trunks and fronds with fresh weight of 250 kg) were placed on the soil surface inside the mesh containers, Three containers were used per plot and they were replicated four times to give a total of 12 units. One container per plot was sampled at six-month interval. Materials on the soil surface within the containers were collected and litter fragments/light fraction separated using 2 mm mesh polyvinyl sieve. The bulk sample and light fraction were weighed and subsampled for moisture content determination. The weights of light fraction was also quantified and analysed for nutrient content.

In the case of the C/P materials, the bulk samples were treated as C/S materials except the weight was reduced to 150 kg fresh mass because of the large volume of material.

Chemical Analyses

Analyses of C, N, P, K, Ca and Mg were determined using standard analytical procedures.

Determinations of lignin and cellulose in palm residues were carried out following the procedure of the American Society for Testing and Materials (ASTM).

Silica was determined gravimetrically by ashing with concentrated HCl and HNO, following the method of the Central Analytical Laboratory, Wye College, U.K.

Data Analysis

Percentages of the remaining dry matter of decomposed materials were analysed by ANOVA to determine differences in decomposition of the oil palm components studied with respect to the position in the pile of oil palm residues in the field.

Decomposition rate constants were calculated using the single exponential function:

$$W_t/W_o=W_oe^{-kt}$$ (Anderson and Ingram, 1993)

where W_t is the amount of the initial mass (W_o) remaining at time 't'

All statistical analyses were performed using SigmaStat statistical software package (Jandel Scientific Software, 1994).

RESULTS AND DISCUSSION

Resource Quality of Oil Palm Residues

Table I shows the results of chemical analyses and resource quality characteristics of the freshly oil palm residues placed in litter bags for decomposition studies. Of all the residues, the leaflets have the highest resource quality which had the highest nutrient concentrations of N, P, Ca and Mg except K which was higher in the rachis and trunk. The leaflets contained a high N concentration and had a C:N ratio of 18. In contrast, the rachis, trunk and roots contained low N and the respective C:N ratios were far higher with values of 107, 82 and 117 respectively. The C:N ratio indicated resource quality ranked in the order: leaflets > trunks > rachises > roots. The last three materials were considered to be low quality resources in terms of their decomposition rate potential.

The lignin concentration was also highest in the leaflets but the lignin:N ratio indicated a similar ranking for resource quality to C:N ratio. The oil palm lignin concentrations of leaflets, rachis, trunk and roots were similar to lignin concentrations of 20%-30% for forest leaf species reported by Singh (1969).

Silica was higher in the leaflets with a value of 1.55% compared with the rachis, trunk and roots with 0.39%, 0.84% and 0.52% respectively. A high silica content might affect decomposition by soil fauna but is unlikely to influence microbial decomposition (Ma and Takahashi, 1989). However, there is no clear quantitative information on this in the literature.

TABLE 1. RESOURCE QUALITY CHARACTERISTICS OF FRESH OIL PALM RESIDUES

Nutrient	Leaflet	Rachis	Trunk	Root
		(%)		
N	2.66	0.44	0.58	0.41
P	0.15	0.05	0.06	0.04
K	1.33	1.80	1.86	0.90
Ca	0.62	0.55	0.38	0.07
Mg	0.26	0.17	0.15	0.11
SiO_2	1.55	0.39	0.84	0.52
C	47.91	47.34	47.77	48.00
C/N ratio	18	107	82	117
Lignin	24.96	20.96	18.14	23.77
Lignin/N ratio	9.38	47.64	31.28	57.98
Holocellulose	69.86	73.85	83.06	67.39

Decomposition Patterns of Oil Palm Residues

Results are first presented for decomposition of individual materials using litter bags to measure mass losses and nutrient mobilization and then for the bulked C/S and C/P materials.

Decomposition of leaflets. *Figure 1* shows the decomposition patterns of leaflets placed at the top, middle and bottom of the residue pile. The material decomposed very rapidly *in* all three locations with 80%-95% mass losses after 12 months. There were, however, significant differences with the material at the top (17.34% remaining) showing significantly lower ($P < 0.05$) mass losses than in the middle (9.68%) and bottom (3.74%) of the pile.

Some of the samples were attacked by termites and this is reflected in the large standard errors for means in the eighth month, Most of the undecomposed leaflet materials after 12 months were midribs which have a similar quality to that of rachis. The decompo-

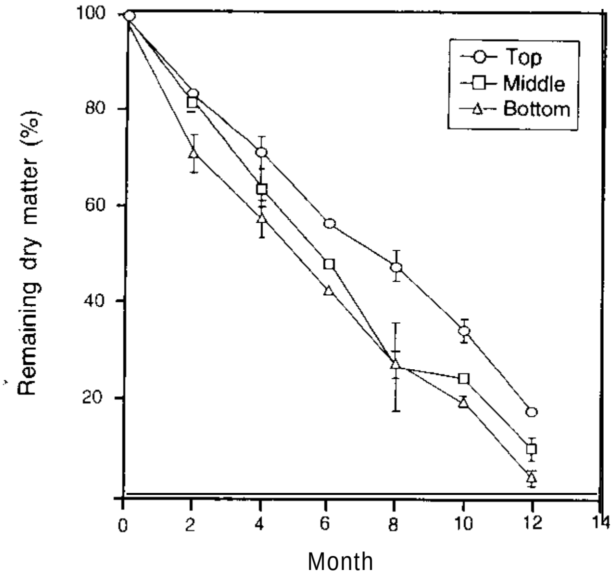

Figure 1. Remaining dry matter (% of original) of leaflets at various positions in the residue piles.

sition rate of leaflets in the residue piles showed a decline in the following order: bottom > middle > top position

Decomposition Of rachises. The decomposition rates of rachis at the top, middle and bottom of the residue pile are shown in *Figure 2*

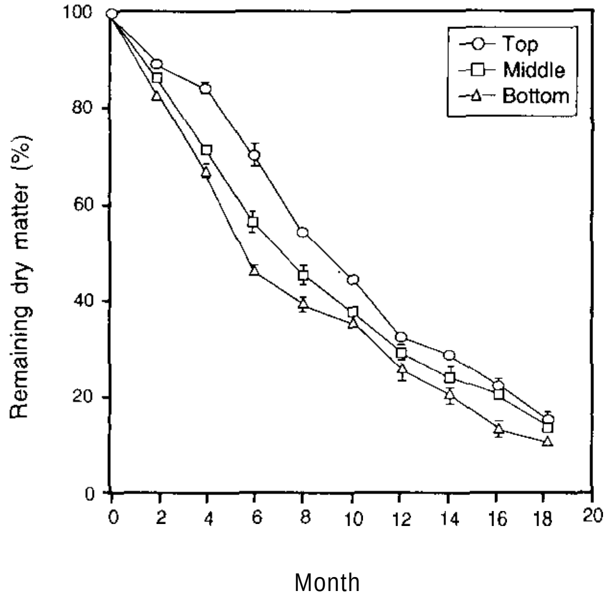

Figure 2. Remaining dry matter (% of original) of rachises at various positions in the residue piles.

After 12 months, the materials had lost about 70%-75% of their initial masses and 85%-95% by 18 months. The decomposition over 12 months showed almost constant loss of the initial mass for all the positions. At 12 and 18 months, the dry matter remaining at the top of the residue pile was significantly higher ($P < 0.05$) than the materials placed at the bottom position. The difference was probably due to rapid decrease in the **mass** of rachis placed at the bottom during the early stage of decomposition.

Over the first 12 months, the rachis materials at the top of the pile decomposed more slowly but the effect of location was less marked over the last six months of the experiment. This was probably due to the thick legume covers which reduced the microclimate differences between the positions in the residue pile, and also to most of the litter bags at the top and middle positions slowly subsiding to the ground as the residue pile decomposed. It was observed that legumes and weeds covered all the samples after six months. Also, during this early period, there were more days with rain and the moisture contents of the rachises at 12 and 16 months showed no significant difference between position (Table 2).

There were some indications of decreased

TABLE 2. MOISTURE CONTENT (%) OF RESIDUAL MATERIALS AT VARIOUS POSITIONS IN THE RESIDUE PILES

Month	**Position**	**Moisture content (%) of residual material**		
		Leaflets	**Rachis**	**Trunk**
4	Top	28.0 (3.97)	26.5 (1.60)	73.1 (3.231
	Middle	57.9 (3.06)	51.3 (5.59)	71.3 (2.44)
	Bottom	65.8 (2.36)	56.4 (4.07)	75.2 (2.53)
	LSD (0.05)	10.23	13.11	8.82 (n.s)
8	Top	19.3 (0.35)	48.4 (1.67)	77.3 (3.79)
	Middle	49.4 (4.92)	71.4 (2.47)	86.5 (2.48)
	Bottom	54.7 (2.48)	73.4 (0.75)	86.9 (2.06)
	LSD (0.05)	10.20	5.68	9.19
12	Top	49.3 (5.22)	62.4 (5.04)	67.7 (2.56)
	Middle	45.7 (3.24)	67.1 (1.49)	76.4 (2.30)
	Bottom	53.3 (0.69)	63.2 (2.89)	79.4 (0.98)
	LSD (0.05)	11.42 (n.s)	11.07 (n.s)	6.50
16	Top		65.3 (1.08)	77.0 (0.73)
	Middle		65.1 (2.17)	78.7 (0.82)
	Bottom		63.7 (3.50)	78.5 (1.34)
	LSD (0.05)		7.87 (n.s)	3.20 (n.s)

Notes: Figures are means of four replications. Figures in parentheses are standard error of means.

decomposition rates over the last six months of the study. By this time, the undecomposed materials, consisting mainly of the outermost layers of the rachises, or 'skins', and bases of the fronds or the 'petiole' parts which were larger when compared with other sections. The 'skins' seemed semi water repellent due to its very smooth and waxy surface, especially at the base of the 'petiole' section The decomposition ofrachis started from the inside which consisted of soft parenchyma and vascular bundles.

Decomposition of trunks. *Figure 3* shows the decomposition rates of trunks placed at the top, middle and bottom of the residue pile. A similar pattern was observed as with the rachis with rapid decrease in dry matter during the first 12 months. At 12 months, the dry matter remaining was about 15%-30% Decomposition rates of the trunks to 12 months showed significant differences ($P < 0.05$) between placements. The trunks at the bottom and in contact with the ground decomposed significanly faster ($P < 0.05$) than materials at other positions. The mean of the remaining dry matter after 18 months was about 12%. A similiar value for the residual mass of rachises was observed after the same time.

During the early stages of decomposition, the inner part of the trunks which mainly comprises soft parenchyma tissue and vascular bundles were first to decompose. The parenchyma tissues rapidly decomposed leaving behind significant amounts of vascular bundles. At the later stages of decomposition ofthe trunk, the rate was slower than at the early stage as the residual materials then comprised mainly the outermost lignified layer of the trunk, or 'bark', with partially decomposed vascular bundles

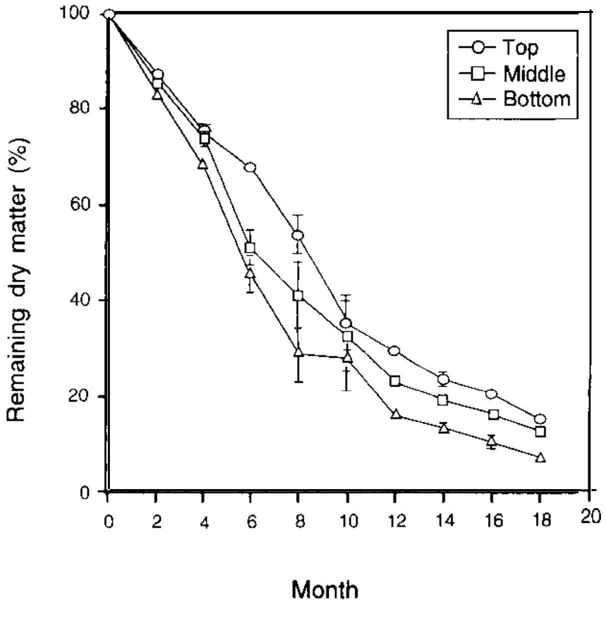

Figure 3. Remaining dry matter (% of original) of trunks at various positions in the residue piles.

Decomposition of roots. *Figure 4* shows the decomposition patterns of primary and secondary roots buried at the old avenue and frond pile locations. A slow decrease in dry weight was observed during 12 months decomposition. After six months, the dry matter losses was about 30% at both locations which remained about 70% dry matter from the initial mass.

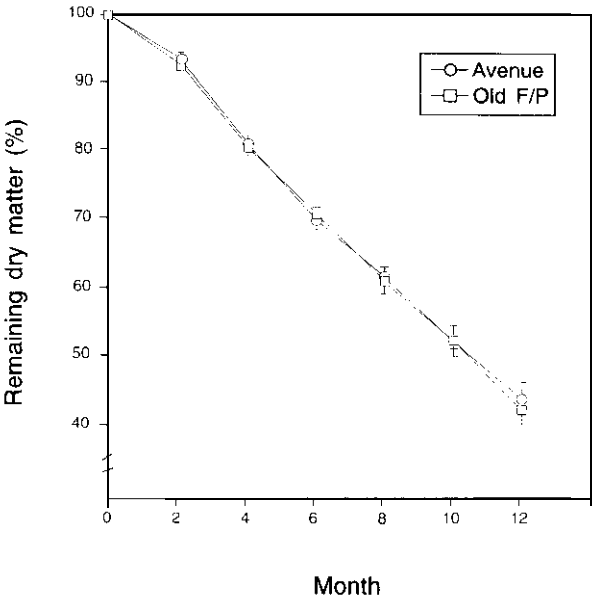

Figure 4. Remaining dry matter (% of original) of roots buried in old avenues and old frond piles locations.

There was no significant difference in the remaining dry matter between the roots buried at the old avenue and old frond pile. This suggests that the chemical characteristics of soil and the availability of microflora and microfauna or the microbial biomass in the soil did not influence the decomposition processes even though the old frond pile location was more fertile with higher microbial biomass than the old avenue.

After 12 months, about 43% of the inital root mass remained, consisting mainly of the outer epidermis and lignified hypodermis and endodermis. The old roots, particularly the primaries, were still strong and elastic and persisted long after they have died. It was observed that when a root dies, the cortexdegenerates, leaving a tubular hypodermis containing loose cortical fibres and the woody stele (Hartley, 1988).

Decomposition rate constants of oil palm residues. The decomposition rates were approximately linear. The rate constants, measured as percentage loss per day over the experimental period, are shown in ***Table 3.*** The results showed that the leaflets, rachis and trunk decomposed slower at the top of the residue piles. The leaflets showed the highest mean mass loss of 0.22% day-i than rachis and trunk with similar rates of about 0.17% day-i. Given the differences in the resource quality of these materials (***Table*** I), the similarity of the decomposition rates was rather surprising, especially in view of the differences in resource mass for leaflets, rachis and trunk. Roots, which had lower resource quality than the above-ground materials as expected, showed lower decomposition rates in both the avenue and old frond pile with a mean of 0.13% day-i. On this basis, the rachis and trunk were estimated to take less than 20 months for total decomposition, whereas the roots will take about 25 months.

TABLE 3. DECOMPOSITION RATE CONSTANTS, ‘k’ (% day’), OF OIL PALM RESIDUES IN VARIOUS POSITIONS IN THE RESIDUE PILES

	Position			
Residue	**Top**	**Middle**	**Bottom**	**Mean**
Leaflet	0.22	0.22	0.23	0.22
Rachis	0.16	0.17	0.17	0.17
Trunk	0.16	0.17	0.18	0.17
	Location			
	Old avenue	Old frond pile		Mean
Roots	0.13	0.13		0.13

Decomposition of the bulks C/S and CIP materials. Table 4 shows the remaining dry matter of the bulks C/S and C/P materials and dry matter of light fraction carbon at different sampling times. Light fraction carbon is defined as the carbon that is less than 2 mm size and not bound to the mineral soil, It is considered litter in the soil and represents the undecomposed organic material. After six months, the remaining dry matter of the bulk C/S material was about 65%. The value was quite close to the mean value of remaining dry matter of rachis and trunk which was about 55%. Similarly, at 12 and 18 months, the

TABLE 4. PERCENTAGE REMAINING DRY MASS OF C/S AND C/P MATERIALS AND DRY MASS OF LIGHT FRACTION (< 2 mm) ON THE PLOT (estimated by quadrat sampling)

	Remaining dry mass (%) after months		
Material	6	12	**18**
C/S	65.23 (0.97)	34.25 (4.88)	21.70 (2.26)
C/P	35.95 (1.67)	15.28 (1.36)	7.80 (0.82)
	Light fraction (kg quadrat^{-1})		
Month	6	12	18
Material			
C/S	Not measured	3.84 (0.425)	5.94 (0.955)
C/P	"	4.62 (0.385)	2.32 (0.313)

Notes: Figures are means of four replicates. Figures in parentheses are standard errors of means.

remaining dry matter of the bulk C/S residual materials were about 35% and 20% respectively, slightly higher by about 10% than the remaining dry matter of intact rachises and trunks studied separately using litter bags. The slower decomposition of the C/S materials especially the chopped trunks were affected by the larger pieces of these materials than the intact resources. This means the size of residue treatment has an effect on the decomposition rate and the litter bags method used for decomposition studies was acceptable.

As expected, the C/P materials decomposed faster than those of C/S materials due to its treatment. After six and 12 months, about twice the amount of C/S material remained compared to C/P material and a difference of about 3:1 emerged at 18 months when most of the C/P material had decomposed. It was expected the C/P materials will release nutrients reserve faster than the C/S materials and more organic matter or light fraction carbon accumulate on the soil surface in the C/P plots. However, due to faster decomposition, the light fraction carbon will also be lost rapidly. It was found after 18 months that the light fraction carbon under the C/P materials had only about 50% remaining than that the light fraction carbon under the C/S materials.

The decomposition of bulk C/S materials obtained in this study paralleled the finding of Samsudin Amit et al. (1993) who reported the decomposition period of the shredded and partially burnt palm trunk materials as about 10-11 months.

The high quality resouces such as spear leaf, cabbage or the top part of the trunks decomposed faster than the lower quality materials such as the bottom part of the trunks, or trunk bases, and fronds bases, which were more resistant to decomposition. On the average, most of the oil palm residues will decompose within 12-18 months whereas some of the low quality materials may take much longer, even up to two years.

Nutrient Release Patterns of Oil Palm Residues

The rate at which nutrients are released from decomposing materials will depend on whether they are combined in the components as with the cell lumen (N, Mg and P), with structural materials (C and Ca) or are largely present in ionic form in the cell vacuoles (K). Because of these differences in form and location, decomposition (KCL) will have different effects on the nutrients and timing for their release.

Nitrogen. N in the plant is an essential constituent of proteins, nucleic acids and various coenzymes which are mainly present in the organic form. During decomposition, the organic N is mineralized to inorganic form and the rate of decomposition or biodegradability mainly depends on the C:N ratio of the material. A high quality material with a low C:N ratio decomposes rapidly. However, a low quality material with a high ratio, or limited N, decomposes only slowly with much of its N initially incorporated into the microbial pool.

Figure 5a shows the N release from leaflets. The release was rapid, roughly proportional to the dry matter losses. After six months, the N remaining in the leaflets ranged from 32%-48% with a mean value of 40% at the various positions in the residue piles. Thus, more than 50% of the N in leaflets was released at the initial stage, within six months of start of decomposition. Over the next six months, more

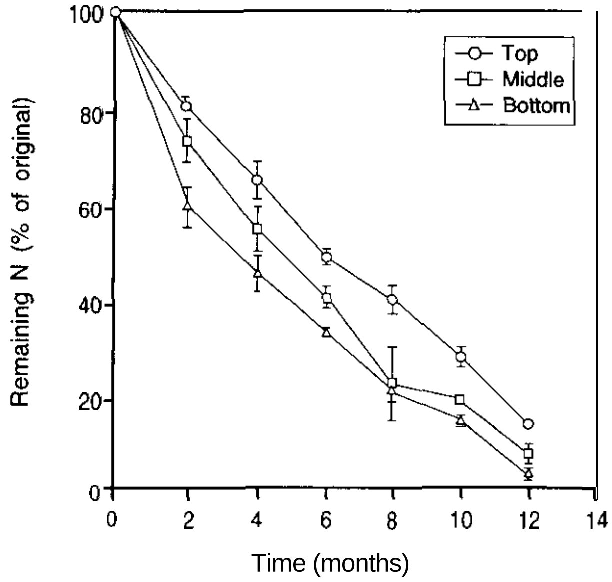

Figure 5a. N release patterns from leaflets at various positions in the residue piles.

than 85% of N was released. The release of N was actually slightly faster than dry weight loss. The N remaining in the leaflets was significantly different ($P < 0.05$) between the positions of the leaflets in the residue piles. A significantly higher ($P < 0.05$) release of N occurred from the bottom than from the other positions in the residue piles.

In contrast, the rachis (Figure *5b*) and trunk (Figure *5c*) showed slower release of N with mean values of 68% and 76% remaining at the various positions respectively after six months. In terms of timing, the rachis and trunk released about 32% and 24% N respectively after six months. Similarly, with regards to positions, the rachis at the bottom released significantly more N ($P < 0.05$) than the rachis at other positions. However, the release of N from trunk showed no significant differences between positions.

After 12 months, the mean amount of N remaining in the leaflets at the three positions was about 7% whereas the rachises and trunks still retained about 45% N. At 12 months, the N remaining in the leaflets at the top retained significantly higher ($P < 0.05$) N than the leaflets at the other lower positions in the residue piles. However, there was no significant difference between the N in the leaflets in the middle compared with the leaflets at the bottom. Similarly, the rachises at the top retained significantly more ($P < 0.05$) N compared with the other lower positions in the residue piles. Also, the N remaining in the trunks showed significant differences between the three positions in the residue piles.

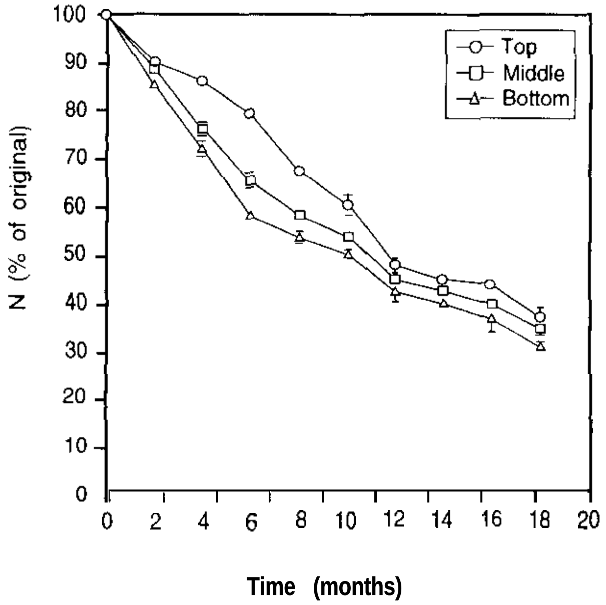

Figure 56. N release patterns from rachises at various positions in the residue piles.

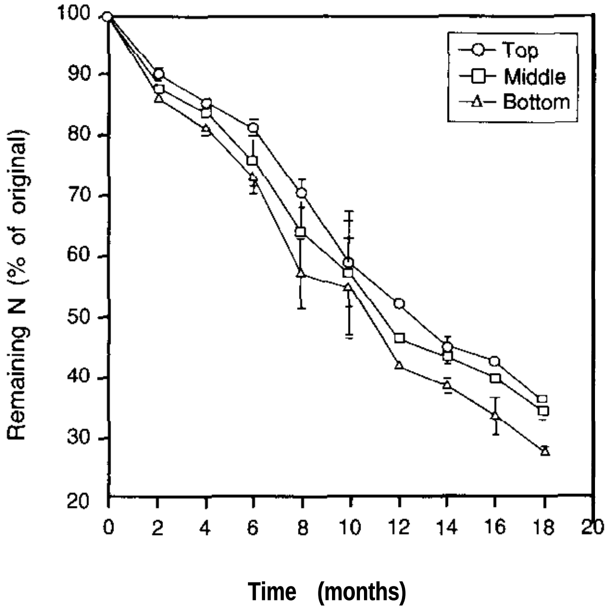

Figure 5c. N release patterns from trunks at various positions in the residue piles.

At the later phase of decomposition, the release rates of N from the rachises and trunks were slower. After 18 months, the mean amounts of N remaining in the rachises and trunks at various positions were about 34% and 32%, respectively. It was observed that the rachises and trunks at the bottom contained significantly less ($P < 0.05$) N than the materials at the top in the residue piles. N losses from the rachises and trunks during decomposition were slower than the mass losses which indicated the N was conserved in the residual materials and only a smaller amount of N released.

None of the resources showed a relative inverse in the % N concentrations indicating that N mobilization was roughly proportional to mass losses. The similarity of decomposition rates for leaflets, trunks and rachises, given the different C:N ratios of 18, 82 and 107, respectively, indicates that physical conditions for decomposition of all of these materials were near optimum and differences in the resource quality of the residues from above-ground was not a main factor determining the carbon and nutrient mineralization rates.

Phosphorus. P is an essential constituent of nucleic acids and phospolipids which are present in organic form. The behaviour of P during decomposition is quite similar to that of N. However, P release *from* oil palm residues differed among the residues and the positions of the residues in the pile.

Figure *6a* shows the P release pattern of the leaflets. The pattern is very similar pattern to that of mass loss and the release of N. After six months, the P remaining was 25%-46% with a mean of 35% at the various positions in the residue piles. More than 50% of the P was released within six months and the P losses were slightly faster than the mass losses. The remaining of P in the leaflets at the various positions were significantly different ($P < 0.05$) between the positions in the residue piles,

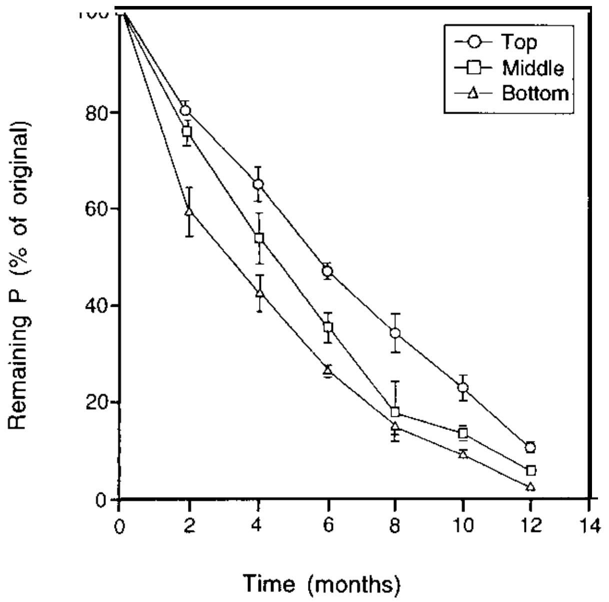

Figure 6a. P release patterns from leaflets at various positions in the residue piles.

From the rachises (Figure *6b*) and trunks (*Figure 6c*), P releases were slower than from the leaflets. The P remaining at six months in the rachises ranged from 65%-75% with a mean of 71%, and in the trunks from 67%.74% with a mean of 67% at the various positions in the residue piles. The rachises and trunks at the top retained significantly more ($P < 0.05$) P than the materials at the bottom in the residue piles.

At 12 months, the P remaining in the leaflets at the various positions had a mean value of about 5% whereas the rachises and trunks stilll retained about 40% and 37%, respectively. At this time, the residual dry matter of the leaflets, rachises and trunks were 10%, 29% and 23%, respectively. The remaining of P in the leaflets, rachises and trunks were significantly different ($P < 0.05$) between the positions in the residue

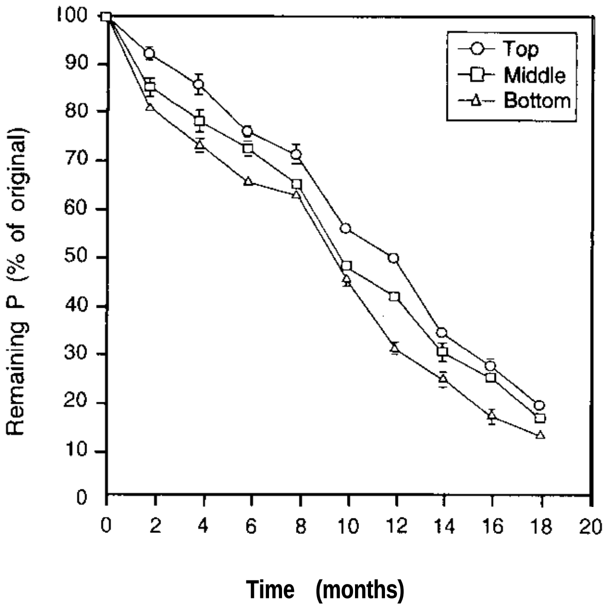

Figure 6b. P release patterns from rachises at various positions in the residue piles.

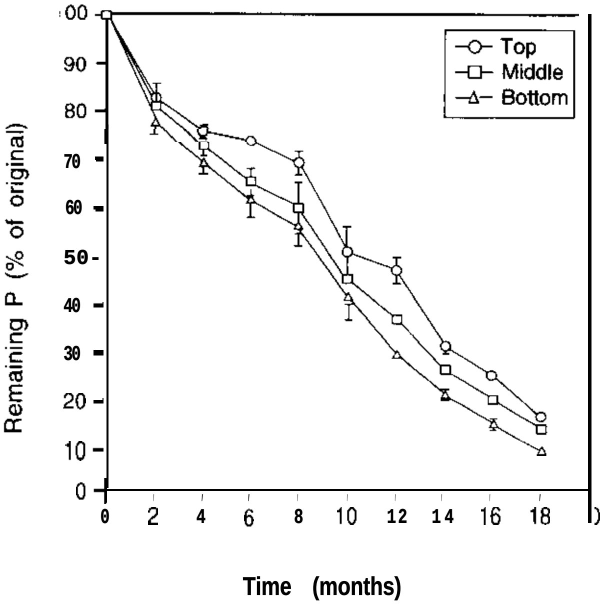

Figure 6c. P release patterns from trunks at various positions in the residue piles.

piles except that the P remaining in the leaflets in the middle and bottom positions showed no significant difference between them.

At the later stages of decomposition (after 18 months), the mean P amount remaining in the rachises and trunks at the various positions in the residue piles were about 14% and 13% respectively. At this time, the mean residual dry matter of the rachises and trunks were 13% and 12%, respectively. The P amounts remaining were significantly different ($P < 0.05$) between the three positions in the residue piles. Throughout the decomposition period of rachises and trunks, the losses of P were slower than the mass losses especially at the early stage but were quite similar over the next 12 months,

Potassium. K is normally found in the non-structural components of plant tissues and mainly in the vacuole of living cells in ionic form. During decomposition of plant residues, K is rapidly leached out, with little interaction with the microbial processes, although the surface area of the residues, or comminution, can affect the leaching rate (Anderson et al., 1983).

K was found to be leached rapidly from all oil palm residues (Figures *7a* to *c*) and was lost significantly faster than the mass loss. Most of the K was lost from the leaflets (Figure *7a*) within six months with more than 75% gone whereas the mass loss was only about 45%.60%. The K amount remaining in leaflets at the top of the residue piles was significantly higher ($P < 0.05$) than in the leaflets at the other lower positions. However, no significant differences were observed between the remaining K amounts in the leaflets in the middle and at the bottom of the residue piles.

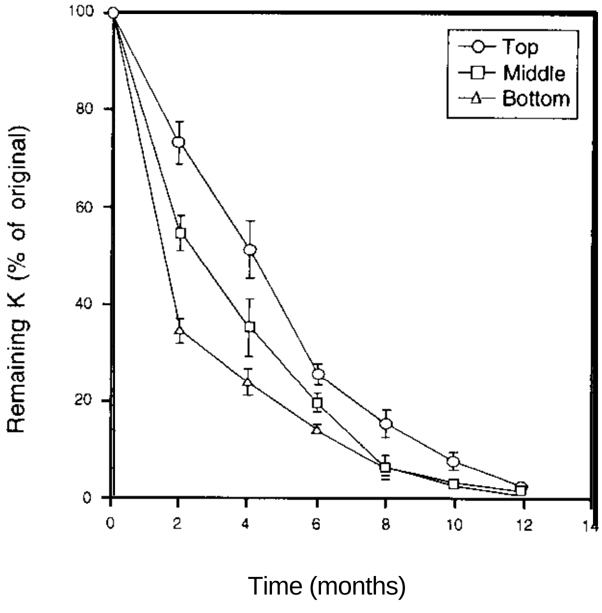

Figure 7a. K release patterns from leaflets at various positions in the residue piles.

The mean remaining K amounts at six months in the rachises (*Figure 7b*) and trunks (Figure *7c*) at the top, middle and bottom positions in the residue piles ranged from 41%-46%. The rachises and trunks at the top retained significantly more ($P < 0.05$) K than the other positions - about 20% more than the materials at the middle and bottom of the residue piles. This showed the differences in release rates of K.

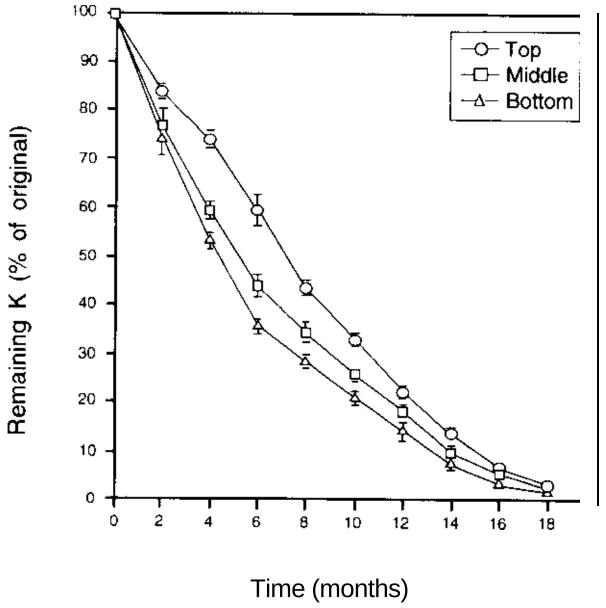

Figure 76. K release patterns from rachises at various positions in the residue piles.

At 12 months, almost all K in the leaflets had been released whereas in the rachises and trunks about 10%-20% of the K still remained. It took about 18 months to release almost all the K to less than 3% in these materials,

The changes in K concentration were different from those of N and P. As K is rapidly leached, the residual material has a lower concentration than the original material. Con-

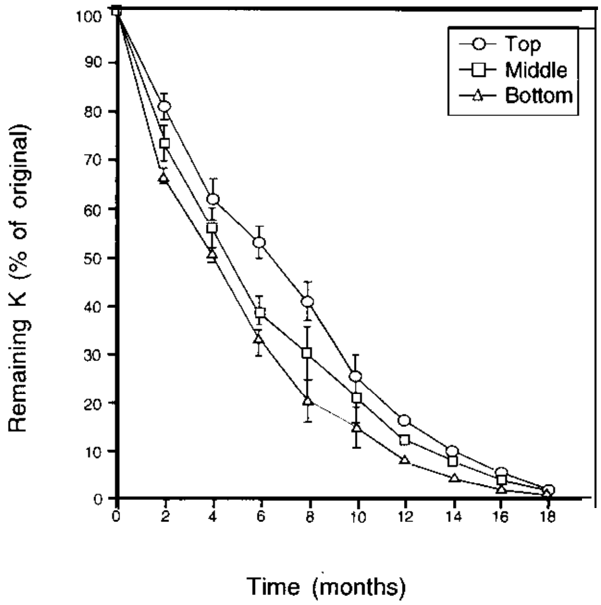

Figure 7c. K release patterns from trunks at various positions in the residue piles.

sequently, the concentration of K in the residues decreased rapidly during decomposition. K release was less affected by the chemical characteristics of the resources than N and P, reflecting the susceptibility of K to physical leaching which is largely independent of microbial activity. Hence, the K loss is only affected by the bulk of the material (the surface area:volume ratio) as can be seen by the slower rates of loss from trunks than from rachises and leaflets.

Calcium Ca *is* mainly found in the middle lamella of plant cell walls (particularly as calcium pectate) and sometimes in inclusion bodies. It, therefore, requires microbial action for release and its release generally tracks carbon mineralization and mass losses (Anderson *et* al., 1983).

Figures *8a* to *c* show the Ca release patterns of leaflets, rachises and trunks, with the release parallel mass losses. As shown in Figure *8a,* at six months, the Ca remaining in the leaflets in the various positions in the residue piles ranged from 48%-60% with a mean of about 54%. The values were quite similar to the remaining mass of the leaflets which ranged from 42%-56% with a mean of 48% (Figure *1*). The rachises (Figure *8b*) and trunks (*Figure 8c*) retained slightly higher Ca than the leaflets with a mean of 63% and range of 61%-64% at the various positions in the residue piles. All the materials at the top retained significantly more ($P < 0.05$) Ca than the materials at the bottom in the residue piles.

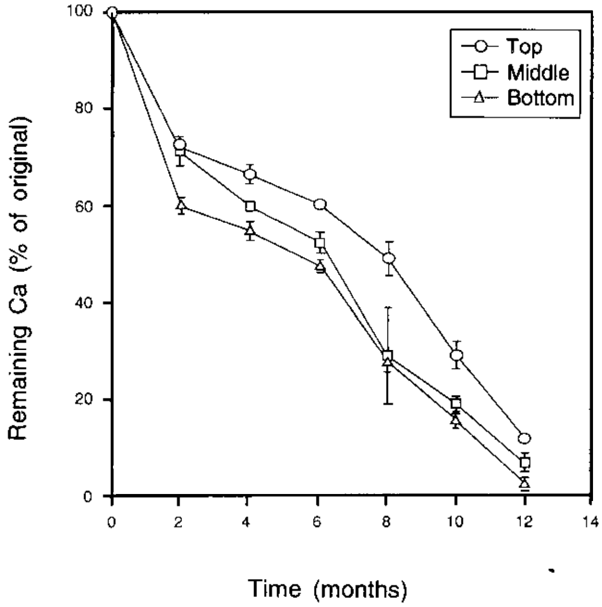

Figure 8a. Ca release patterns from leaflets at various positions in the residue piles.

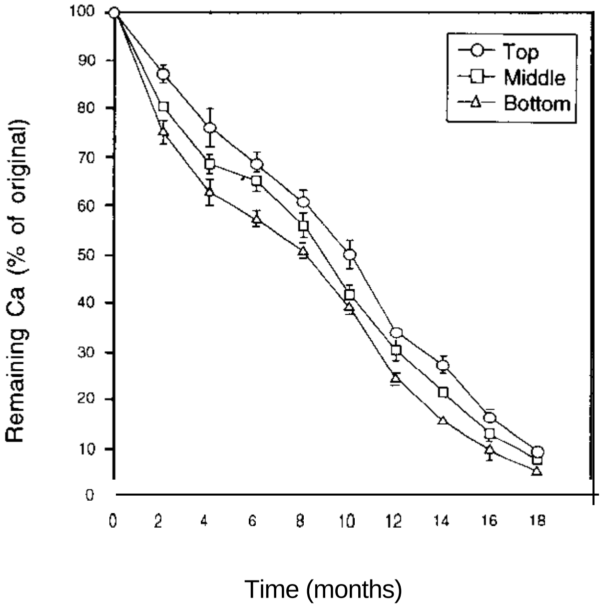

Figure 8b. Ca release patterns from rachises at various positions in the residue piles.

At 12 months, Ca remaining in the leaflets at the various positions had a mean value of about 8% whereas the rachises and trunks had a mean value of about 30%. Further, at 18 months, the Ca remaining in the rachises and trunks at the various positions in the residue

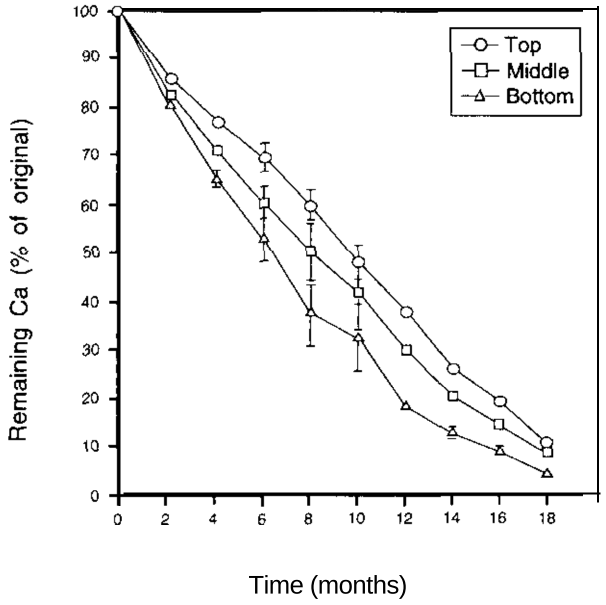

Figure 8c. Ca release patterns from trunks at various positions in the residue piles.

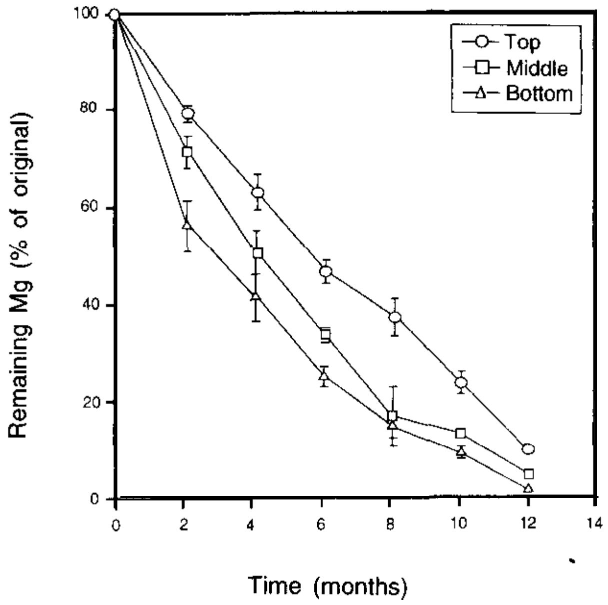

Figure 9a. Mg release patterns from leaflets at various positions in the residue piles.

piles had a mean value close to 10%. This was quite close to that of the remaining dry matter of the materials which was about 12% of the initial mass. It was clear, therefore, that Ca losses closely followed the dry weight losses over the 18 months.

Magnesium The general role of Mg is quite similar to that of K as an enzyme activator, but it is required by even more enzymes than K. Among the many systems requiring Mg is that of fatty acid synthesis, and it is also an essential component of the chlorophyll molecule.

Figures 9a to *c* show the release pattern of Mg from the leaflets, rachises and trunks. The releases followed the same pattern as those of Ca. The rate of Mg release from the leaflets was between the rates of release of K and Ca. However, release of Mg from the rachises and trunks was similar to that of Ca.

After six months, the remaining Mg in the leaflets (*Figure 9a*) at the top, middle and bottom of the residue piles ranged from 25%-47% with a mean of 35%. There were significant differences ($P < 0.05$) between the positions in the residue piles. The release of Mg from the leaflets during 12 months decomposition was faster than the dry weight loss. However, Mg releases from the rachises (Figure *9b*) and trunks (*Figure 9c*) were slower than from the leaflets. The rachises and trunks retained almost twice the Mg of the leaflets with about 65%. The Mg remaining in the rachises and trunks at the top of the residue piles was significantly higher than those in the other positions.

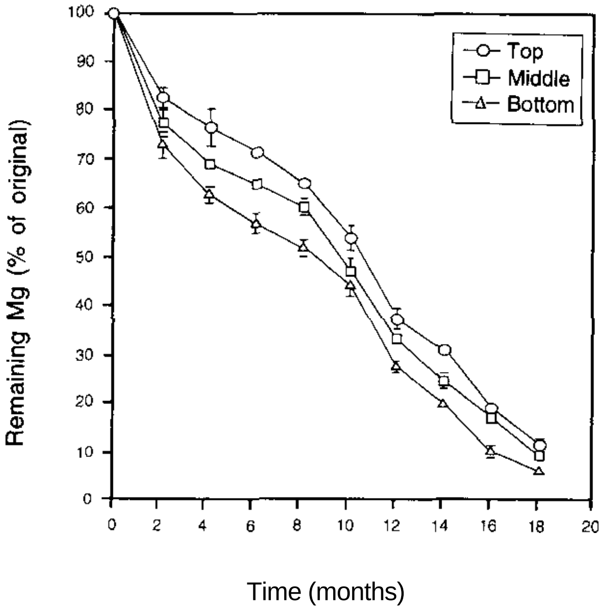

Figure 9b. Mg release patterns from rachises at various positions in the residue piles.

A linear release of Mg from all the palm residues occurred until the later stages of de-

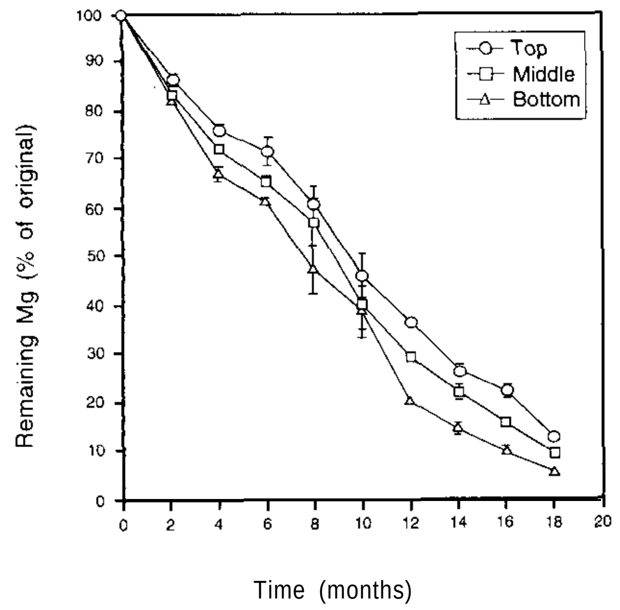

Figure 9c. Mg release patterns from trunks at various positions in the residue piles.

composition. By 12 months, more than 90% of the Mg in the leaflets had been released whereas the rachises and trunks had released only about 70%. Thereafter, at 18 months of decomposition, the rachises and trunks still retained about 10% of their Mg. The releases of Mg from the rachises and trunks during the first 12 months decomposition were slower than their dry weight losses. However, after this, the releases of Mg became faster than the dry weight losses. As mentioned earlier, at the later stage of decomposition of rachises and trunks, most of the residual materials of bark or skin were harder and slower to decompose than the inner softer part. The behaviour of Mg release from the materials were parallel or similar to Ca release throughout the course of decomposition.

The Mg concentration in the leaflets decreased linearly during decomposition. However, the concentration of Mg in the rachises and trunks increased slightly in the middle period of decomposition due to a faster weight loss than Mg loss.

Nutrients Release Patterns of Roots

Figure 10 shows the mean nutrients release patterns of roots in the old avenues and old frond piles.

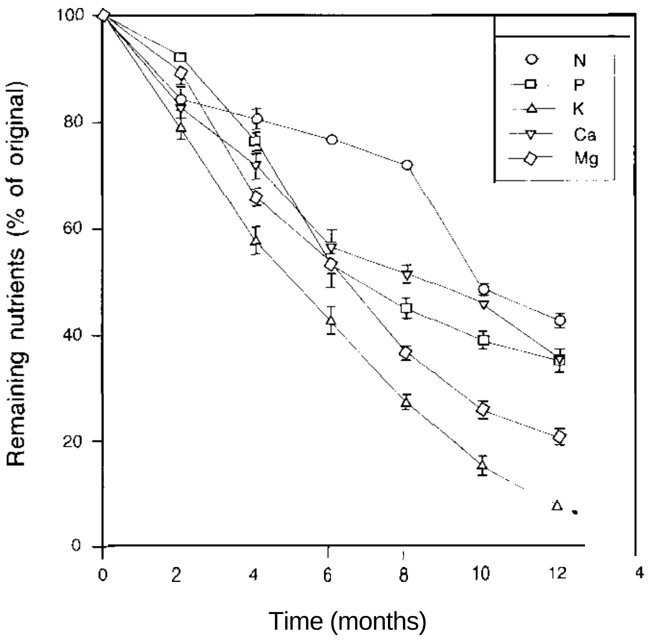

Figure IO. Nutrients release patterns from roots (mean of old avenue and frond piles locations).

After six months, the mean N amount remaining in the roots in the old avenues and old frond piles was about 77%. At 12 months, the roots retained about 42% of N which means the release rate of N from roots was quite similar with release rates of N from the rachises and trunks. This was due to the high C:N ratio of roots which, at 117, was only slightly higher than those of the rachises and trunks.

The release of P after six months at about 47%, and after 12 months at about 65% were in between the rates of release of P from the rachises and trunks.

The K release was 60% after six months and reached > 90% after 12 months.

The remaining Ca in the roots at six months was about 56% and at 12 months about 36%, slightly higher than in the rachises and trunks.

The remaining Mg in the roots at six months was about 53% and at 12 months was about 20%.

As mentioned earlier, the roots, which take an estimated 25 months to completely decompose as compared to the other materials which take less than 20 months, indicating that the nutrient release from the roots was slower and transfer of nutrients to the soil pool was longer.

Factors Affecting the Decomposition and Nutrient Release Patterns During the Study Period

As mentioned earlier, decomposition is regulated by the complex of O, Q and the P variables. The variables operate in a hierarchial series of order: macroclimate > microclimate > resource quality > organism (Anderson and Swift, 1983). The component processes of decomposition – K, C and L – at different magnitudes will affect the decomposition rate and timing for nutrient release because of differences in form and location.

Catabolic processes carried out mainly by microorganisms are the proximate factors of decomposition. The physical and chemical compositions of the resource act as constraints on the availability of carbon and nutrients to the organisms, while the moisture and temperature regimes determine the rates at which these reactions take place. The operation of this hierarchial series of controls was shown by the much of this study. Variations in temperature and moisture were primarily set by seasonality, but the location of the material was related to the microclimate which modified the controls.

The weight loss of decomposing materials was greatly influenced by the abiotic factors. Among the climatic factors, rainfall was the main factor influencing decomposition during the study period. The moisture content of residual materials were related to monthly rainfall distribution. ***Table*** 2 shows the moisture contents of residual material located at the various positions in the residue pile at different sampling date.

The resource quality of the materials studied was that the leaflets were of the highest quality resources and, therefore, decomposed faster than the rachises, trunks and roots. In addition, a resource with a small mass such as the leaflets, is very sensitive to the microclimate but the rachises or trunks with their large masses tend to maintain a more independent internal microclimate from the location. These characteristics, together with the larger mass of material, are likely to modify the effects of microclimate and decomposition.

During the study period, fungal fruiting bodies and mycelia, normally present on trunks, could be seen ramifying the sponge-like structure of the trunks. Termites were the most active of faunal groups in the plots and rapid removal of materials by their concentrated attacks increased variance of the samples. It was assumed most of the termite population in the study site consisted of wood and litter feeding insects although specific studies were not made to identify the groups. Overall, termite attack was extremely heterogeneous both within and between plots, and no specific studies were made to quantify how they contribute significantly to palm residue decomposition.

CONCLUSION

During the course of decomposition, the decomposition of oil palm residues showed a loss of dry matter in the order:leaflets > rachises = trunks > roots. The leaflets reached t_{50} at six months whereas the rachises and trunks took eight months and the roots 10 months. The decomposition rate constant, ‘k’, of oil palm residues ranged from 0.13% to 0.22% day^{-1} in which the leaflets, rachises, trunks and roots had values of 0.22%, 0.17%, 0.17% and 0.13% day-’ respectively.

The controls regulating decomposition of oil palm residues operated in the rank order: macroclimate > microclimate > resource quality > organisms. The rainfall distribution was the main climatic factor controlling the moisture content of residual materials and affected the rate of decomposition. Variations in temperature and moisture were primarily set by seasonality, but strongly modified by the microclimate within the different locations in the residue piles, at least in the short term until cover was established over the plots. Slower decomposition at the top of the residue piles was due to more rapid drying up of the tissues after rain and this was similar with surface placement of the residues (Parr and Papendick, 1978). Favourable conditions for decomposition are found in the stable moisture microclimatic conditions at the bottom of the residue piles. Consequently, the residues at the bottom decomposed significantly faster than the residues on top,

Interestingly, the calculation of decay constants assumes homogeneity of the resource and the decomposition rate to be independent of mass. The similarity of the 'k' values for leaflets, rachises and trunks indicates that the attributes of resource quality were fairly homogeneous despite apparent gross differences in their masses. However, the C/S or C/P materials did affect the decomposition rates in any way not predictible from the mass losses of the individual resources. The C/P materials showed similar mass loss rates to the C/S materials but there was evidence of decreased mass loss rate with time for the C/S residues which resulted in a residual mass remaining for larger than the intact resources. It is difficult to interpret this from the available information on residue composition. One hypothesis which can be advanced is that there is some interactions between the more or less readily decomposable structural materials in the intact resources which enable even the decomposition of materials such as lignin. When material is shredded, the labile materials may decompose much faster leaving more of the resistant materials in the residue. This does not, however, explain the differences between the C/S and C/P materials. Whatever the mechanism, the net effect is that some components of the tissues remain on the soil surface for up to two years.

Given the overall rapidity of decomposition, however, these differences in rates from the positions in the residue piles contributed little to the general trends in mass losses at the plot scale. On average, most of the oil palm residues decompose within 12-18 months although some of the hardier materials, particularly roots, may take much longer, up to 25 months. Significant accumulation of light organic carbon fraction by the surface soil will provide and release nutrients to the soil.

Nutrients release from oil palm residues showed different release patterns between residue types and nutrients. K was leached rapidly from the leaflets within six months followed by the releases of Mg, Ca, P and N which were slower. The rachises, trunks and roots all showed nutrient releases in the order:K > Mg = Ca > P > N. The overall release of nutrients from the residues was quite fast, particularly for K with more than 70% of the nutrient being lost and transfer to the soil pool within 18 months.

Further research is now required to study these decomposition and nutrient release when the residues, depending on their treatments, come into direct contact with soils under different environments during the replanting of oil palm.

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